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CDF silicon tracking detectors, 1988–2011

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ABSTRACT

On September 30, 2011, the Collider Detector at Fermilab (CDF) finished physics data-taking at the Tevatron proton–antiproton collider. The original CDF silicon tracking detector, proposed in 1981 (SVX) and later replaced and updated (SVX′), was again replaced for Run-2 in 2002–2011 (SVX-II, ISL, L00). These systems operated successfully for many years, performing essential roles in exploring physics at the energy frontier, most notably the discovery of the top quark.

1. Run-1 silicon

The application of silicon detectors for high-energy physics began to be explored in the beginning of the 1980s for detecting short lived particles [1]. An important breakthrough in 1980 was the demonstration of the production of silicon detectors using the standard planar process [2], which led to the industrialization of sensor production.

The addition of silicon tracking to the CDF vertex region was originally presented in 1981 in its technical proposal [3]. The application of VLSI readout [4,5] presented in 1984 was a key step towards realizing the high density silicon trackers at colliders. In spring 1985, a workshop was held to discuss the SVX. Although most of the LEP detectors were installing silicon tracking, application to CDF was considered very challenging due to technical issues such as long SVX strips and 50k signals to read out. The project was pushed forward by development of a new CMOS ASIC, the SVX chip [6], with sophisticated logic added to improve S/N and to allow sparse readout and double-correlated sampling. The SVX proposal was approved in 1988.

The SVX [7,8] employed 8.5 cm long Micron sensors having a $55-60\ \mu m$ pitch. The sensors were DC-coupled since AC-coupling was considered not a sufficiently mature technology at that time. Three sensors were glued to a Rohacell support to form a lightweight ladder structure, and wire-bonded to read out with SVX ASICs (revision D) from one end. Fig. 1 shows an SVX barrel consisting of four ladder layers, each ladder covering a 30° section. Two barrels were installed end-to-end, and operated in the experiment (1992–1993) for an integrated luminosity of $30\ pb^{-1}$. Because of the radiation-soft design of the readout chip, the S/N degraded from 9 to 6 for the innermost layer.

The sensors for the second system SVX′ [9] were AC-coupled with FOXFET biasing [10]. The use of poly-silicon resistors as a biasing method was not pursued since the technology was not considered sufficiently mature at that time. The fabrication technology for the new readout ASIC SVX(rev.H) was UTMC 1.2 μm rad-hard CMOS technology (HP 3.5 μm for SVX(rev.D)), enhancing the radiation tolerance. The SVX′ was installed in 1993 and operated till the end of Tevatron Run-1, 1996.

2. Run-2 silicon

Experience with SVX′ demonstrated the importance of good vertex resolution to maximize the broad physics program at the Tevatron. To cope with the higher luminosity ($10^{32}\ cm^{-2}\ s^{-1}$) and shorter bunch spacing (132 ns in design, 395 ns actual), the inner tracking was re-designed.

Fig. 2 illustrates the Run-2 silicon tracking, which covered the radial region from the beampipe to a radius of 32 cm. The SVX′ region was replaced with SVX-II, which served as the main silicon tracker. The Intermediate Silicon Layers (ISLs) are located outside this, and Layer 00 (L00) was attached on the beampipe. Main sensor parameters and manufacturers are listed in Table 1.

The readout was made with the Honeywell 0.8 μm SVX3 chip [11] where a 46 deep analog pipeline enabled deadtimeless operation.

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2.1. SVX-II

The design and performance of the SVX-II detector are described in detail in Ref. [12]. The goal for SVX-II was to maximize the precision tracking capability by extended η coverage and "3D-vertexing", with precision track information in both $r-\phi$ and Z. Following the success of SVX′, it was important for SVX-II to be aggressive in design.

Fig. 3 shows the photograph of one of the ladders. The ladder was constructed on a structure formed out of boron–carbon fiber and Rohacell foam, to which four silicon sensors were glued. Two BeO ceramic boards were glued on the surface of the sensors at the both ends. The ladders, 5 layers $\times$ 12 sections in ϕ, were attached to beryllium end plates with integrated cooling. The SVX-II was composed of three identical barrels, each being 32 cm long. The total SVX-II length of 96 cm was necessary to cover the long interaction region of the Tevatron (30 cm σ), which improved the event acceptance for top and bottom decays by typically 50% over the 51 cm long SVX′.

An innovative track-based trigger was implemented in a dedicated online processor, the Silicon Vertex Tracking, SVT [13,14]. SVT imposed stringent requirements on the detector design and construction to achieve alignment of the strips parallel to the beam direction to within 100 μrad. Each ladder was constructed to an alignment tolerance of 5 μm and the three barrels were aligned to well within 30 μm by using a common carbon fiber spaceframe. With the success of this new trigger, CDF became competitive with the B factories, opening the sector of heavy hadrons that were not accessible to the B factories.

In order to reduce multiple-scattering of low momentum tracks, the material thickness was minimized by using double sided sensors. In order to provide both optimal three-dimensional vertex resolution and good track reconstruction efficiency, three of the five layers (L0, L1 and L3) employed strips at 90° and the other two layers (L2 and L4) used 1.2° small angle stereo strips. Track reconstruction in the $r-\phi$ plane was given the highest priority, and this was chosen as the p-side of the sensor (as for SVX′) which was the more standard choice at that time. The 90° readout was realized by adopting a double metal structure,

Table 1
Main sensor parameters of Run-2 silicon detectors.

Layer (radius [cm])	Axial/stereo pitch (μm)	Stereo angle	Manuf.
L00 (1.35)	25/–	–	Thompson, Micron
L00 (1.62)	25/–	–	HPK
L0 (2.7)	60/141	90	HPK
L1 (4.3)	62/125.5	90	HPK
L2 (6.7)	60/60	1.2	Micron
L3 (8.4)	60/141	90	HPK
L4 (10.3)	65/65	1.2	Micron
ISL (20, fw)	112/112	1.2	HPK
ISL (23, cnt)	112/112	1.2	HPK
ISL (29, fw)	112/112	1.2	Micron

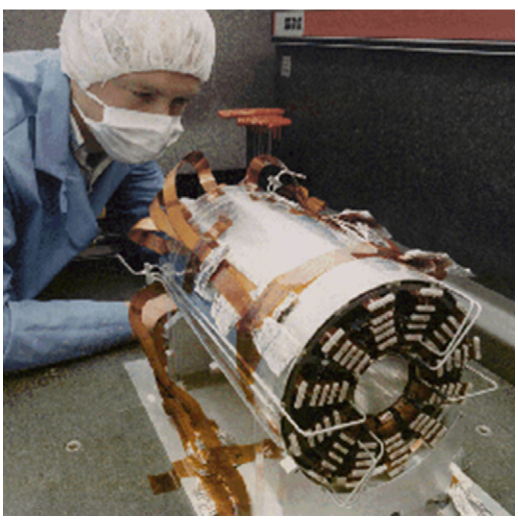

Fig. 1. One of the two completed SVX barrels.

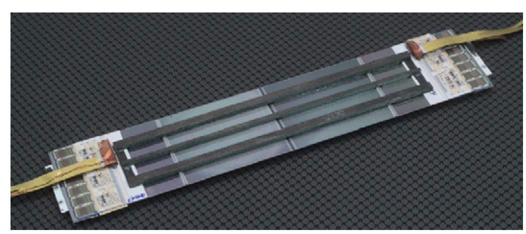

Fig. 3. One of the SVX-II ladders. The length is 32 cm.

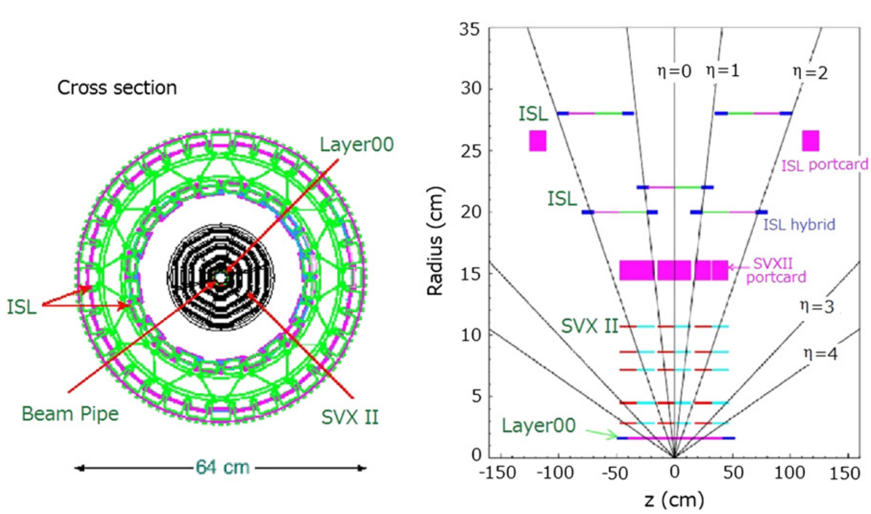

Fig. 2. Run-2 silicon tracking system, consisting of SVX-II (five double-sided), ISL (one in the central and two double sided in the forward), and L00 (one single sided) detectors.